

Major survey provides new data
on hazardous waste management
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CHEMICAL & ENGINEERING

NEWS

RADON

Studies, experts confirm
threat of lung cancer
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News of the Week

- The West German Chemical Industry Association has suspended Imhausen Chemie, which is charged with supplying Libya with plant and technology for producing chemical weapons. Page 4
- Bush Administration's environmental policies get off to a fumbling start. Page 5
- U.S. 13-year-olds place last in mathematics and close to last in science in international assessment of achievement in those fields. Page 5
- Negative impact of leveraged buyouts on R&D confirmed by NSF data. Page 6
- Emissions of chlorofluorocarbon refrigerant CFC-12 to be reduced via recycling, and a new blend of compounds may offer a substitute for it. Page 6

Business

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Establishment of an International Chemical Warfare Authority is proposed to help stem the spread of chemical weapons. Page 21

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Prominent chemists review frontiers in chemistry in symposium at AAAS annual meeting held last month in San Francisco. Page 24

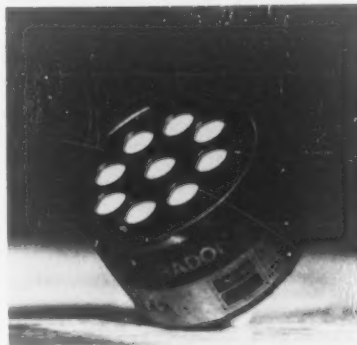
A scanning tunneling microscope has been used to obtain images of the internal structure of an isolated molecule. Page 27

Genetic evidence accumulates that all humans today trace back to one woman who lived about 200,000 years ago. Page 28

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News Focus

Most studies and scientists agree that radon poses a cancer risk, but debate continues over the action level set by EPA for the indoor air pollutant. Page 7

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LETTERS

Gasoline additive

SIR: In his long letter (C&EN, Dec. 5, 1988, page 3) William J. Wells III presents strong technical arguments supporting the use of ethyl *tert*-butyl ether (ETBE) as a gasoline additive in lieu of or in addition to methyl *tert*-butyl ether (MTBE). He skirts the real issues, however: costs and federal tax support of the grain ethanol business, which exists only because of the special tax subsidy granted to production from facilities employing this inefficient and uneconomical route to ethanol.

Without this crutch, alcohol from grain is not competitive with petrochemical source ethanol. Further, despite its stated technical advantages, ETBE has not been able to gain a foothold in the market, even when it is made from much cheaper petrochemical ethanol. Congress should not extend this unfair gift to the grain farmers and alcohol producers by extending it to ETBE produced from grain.

E. H. Ivey
Houston

Nuclear waste

SIR: In his letter (C&EN, Nov. 7, 1988, page 66), Jack Jacox, from the nuclear field of technical consultation and public relations, misinforms and misleads readers with his statement, "There is no long-lived radioactive waste! The long-lived isotopes are fuel that should be reprocessed.... Other rational developed nations are reprocessing their spent fuel." First, among the aforesaid isotopes are some that are not used as fuel, such as cesium-135 and iodine-129 with half-lives ranging up to millions of years. Second, although reprocessing can recover most of the original fissile elements for reuse, about 2% of the plutonium and other long-lived radionuclides inexorably accumulates as a residue that must be permanently stored in isolation from the environment. [MIT faculty, "The Nuclear Almanac," Addison-Wesley Publishing Co., Reading, Mass., page 260 (1984).] Third, the only commercial U.S. reprocessing plant, in West Valley, N.Y., was closed down in 1972 because contamination of the plant, site, and workers became unmanageable, including leakage of plutonium into the Springville dam three miles away. According to the Department of Energy's Willis Bixby, currently in charge of the cleanup, \$391 million has been spent so far, and he estimates the total cost at \$1 billion (the same as for

Three Mile Island). A federal court recently ordered DOE to clean up similar contamination at the government reprocessing plant in Fernald, Ohio, which DOE estimates will also cost \$1 billion, part of its estimate of \$175 billion to clean up 17 federal nuclear sites. (Santa Barbara News Press, Dec. 3, 1988).

Fourth, Jacox's loose categorization of all long-lived isotopes as fuel includes plutonium, which along with uranium can serve as fuel in fast-breeder reactors, where additional plutonium is also created from the uranium. But practical fast breeders are currently pie-in-the-sky. They are being "abandoned as a costly dead end" [Worldwatch Institute, "State of the World 1987," W. W. Norton & Co., New York, page 79 (1987)], related to such risks as the spontaneously inflammable liquid sodium used for heat transfer, and the tons of plutonium in a single reactor load invading the environment by leakage, meltdown, and hydrogen explosion. The half-life of plutonium is 24,400 years, and its toxicity is such that 1 lb finely divided in fallout and inhaled as dust from an atom bomb explosion or a hydrogen explosion of a reactor as at Chernobyl [Hawkes N., et al., "Chernobyl: the End of the Nuclear Dream," Random House, New York, page 98 (1986)] contains about 10 million lung-cancer doses for nonsmokers and 2 billion doses for smokers [Gofman, J. W., "Radiation and Human Health," Sierra Club Books, San Francisco, page 488 (1981)]. A Lawrence Livermore study in 1986 found that Chernobyl emitted as much long-term radioactive nuclides on the planet's surface as all previous explosions of nuclear bombs and tests. The small hydrogen explosion at Three Mile Island fortunately did not breach the building [Eisenbud, M., "Environmental Activity," 3rd ed., Academic Press, New York, page 369 (1987)].

The only commercial breeder built in the U.S., the now defunct Fermi 1, suffered a partial meltdown in 1966, and a classified report stated that a maximum radioactive release at this plant could lead to 66,500 deaths ["Possible Effects from a 300 MW Nuclear Reactor Located at Laguna Beach, Michigan," Atomic Energy Commission (1957)]. In a "major policy decision," Britain in 1997 will shut down Dounreay, "probably the only operating fast reactor fuel reprocessing plant anywhere," and in 1994 will shut down its neighboring prototype fast-breeder reactor. Fast-breeder R&D spending "will be pared to about \$17 million annually, less than a fifth of

Radon Tagged as Cancer Hazard By Most Studies, Researchers

Although some scientists argue that EPA's action level of the radioactive gas in homes is too low, it seems clear that moderate or high concentrations of radon pose major lung cancer risk

David J. Hanson, C&EN Washington

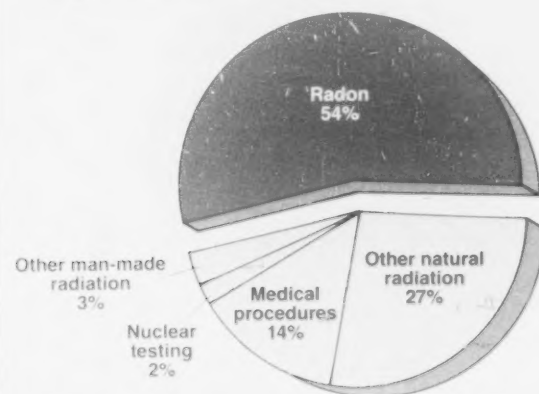
In three short years, the radioactive gas radon has progressed from relative obscurity to a cause of high anxiety as an indoor air pollutant. Behind this anxiety are highly publicized health risk projections indicating that the likelihood of dying from lung cancer increases if radon is present in the home (radon is a decay product of uranium, which occurs naturally in soil in many parts of the U.S.). Public reaction to this health risk has ranged from fright to little concern, and many people have raised questions about the way the issue has been handled by the government. But one thing seems clear: Although a number of questions remain about the risk at low levels of exposure, most researchers agree that moderate or high levels of radon are a health problem.

The Environmental Protection Agency has taken the lead in making the public aware of the radon risk, although other federal agencies and many researchers are contributing information on the subject. In 1985 EPA evaluated the existing data on the lung cancer risk from radon exposure, and recommended that residents consider taking some kind of remedial action if the radon level in their houses exceeds 4 picocuries (pCi) of radon per liter of air. But EPA's analysis isn't the only one available, and there is a large volume of data, human and animal, to consider when making a decision about radon.

That radon might cause health problems has been known for a long time. Reports of a "miners' disease" suffered by underground miners in central Europe as far back as the late 1500s are now assumed to be cancer. But not until the 1930s was it recognized that radon played a role in the miners' lung cancer problem.

The first detailed studies of radon effects on miners were done in the 1950s in the U.S., when the Atomic Energy Commission began looking into the problem at its Grand Junction, Colo., operation. An occupa-

Radon makes up most of normal background radioactivity



tional health standard was actually set in 1955 at 10 pCi per L of radon in air by the International Commission on Radiological Protection and at 100 pCi per L by AEC. It also was discovered that the high incidence of lung cancers in underground miners probably was caused by radiation from radon, rather than by the gas itself.

However, it wasn't until about 1970 that radon's potential risk to a wider population became known. At that time the Public Health Service (PHS) and the predecessors to the Department of Energy began looking into the discovery that homes built on reclaimed land over uranium mill tailing deposits were building up high levels of indoor radon. Later, a similar increase in radon levels was found in houses built on other reclaimed land from mining operations, particularly phosphate mines in Florida. At the time, radon contamination in houses was believed to be mostly associated with industrial mining and mill-



Guimond: four key elements to strategy for tackling radon

ing. Although there were some early indications that the problem was more pervasive, nothing was done.

The watershed event occurred in 1984. In December of that year the home of Stanley Watras was discovered to contain stupendous amounts of radon. Watras was an engineer working on the Limerick nuclear power plant in eastern Pennsylvania. He found that he was setting off the plant's nuclear monitors upon entering the plant in the morning. When the source of the radioactivity was traced, it was Watras' home, which measured a whopping 2700 pCi per L in the basement, a far higher amount than most miners were ever exposed to. The media attention generated by this discovery led to the present public awareness of radon.

Richard J. Guimond, director of EPA's Office of Radiation Programs, has been studying the problem of radon for nearly 20 years. He says after the Watras case, EPA Administrator Lee M. Thomas asked him to put together a strategy for investigating radon levels in Pennsylvania and for determining how significant the radon problem was nationally.

"That strategy, which is basically the one we are still following, has four key elements," Guimond says. "First was problem assessment. Basically, it is to sort out how many houses are affected and what are the levels of radon in them. Second is mitigation and prevention. We didn't want to be in a position of telling people they had a radon problem and a health risk if we didn't have good ways for them to fix it. Third was developing a testing program for companies that wanted to test homes for radon so they would meet some minimum standard. Last was public education. We felt we needed to give the public as good an understanding as we could of the magnitude of the problem, what it means to them as individuals, and how they can sort out whether they have a radon problem or not."

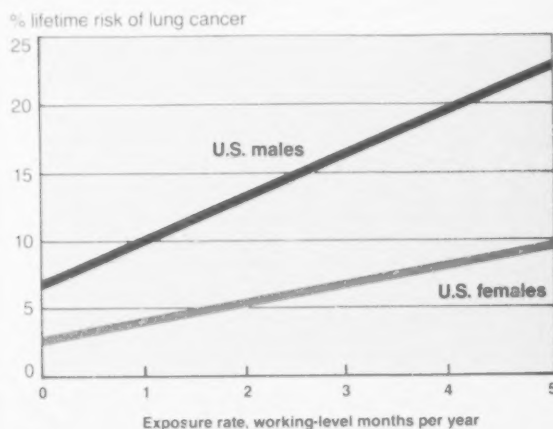
The data used to determine whether people have a health risk or not come primarily from studies done on underground miners in the U.S. and other countries, especially Canada, Sweden, and Czechoslovakia.

In every instance, the studies showed an excess in deaths from lung cancer when miners were exposed to high levels of radon and its decay products, called radon daughters or progeny. By using what is known about the radon exposures of these men and extrapolating these data down to the expected lifetime risk an individual might have from radon levels in the home, researchers have come up with the lung cancer estimates put forward by EPA and others.

EPA has made what may be the highest estimates of lung cancer deaths caused by radon. In its citizen's guide EPA says that from 5000 to 20,000 deaths annually may be attributed to radon and radon progeny. The Committee on Biological Effects of Ionizing Radiation of the National Academy of Sciences did a major study of radon and other alpha-emitters a year ago, and its analysis of the health risk from radon put maximum lung cancer deaths at about 13,000 per year. In 1984, the National Council on Radiation Protection & Measurements (NCRP), a nonprofit corporation chartered by Congress to, in part, develop and disseminate information on radiation, published an analysis of the health effects of radon and radon daughter exposure. That report puts total lung cancer deaths from radon at about 9000 annually.

In addition to the gross observations that more underground miners get lung cancer and the statistical analysis that defines just how much more at risk miners are, there also have been animal studies demonstrating that radon causes lung cancer. For years Fred T. Cross, a senior staff scientist at Battelle Pacific Northwest Laboratory in Richland, Wash., has been looking at how radon causes cancer in animals. "We see effects exclusively limited to the lungs," Cross says. "These studies have been going on since the late 1960s, so we have collected quite a bit of data on the effects of indoor radon. In our experiments, we have exposed animals to mixtures of radon and radon daugh-

Risk of cancer from radon progeny at low exposure levels



Source: National Academy of Sciences report "Health Risks of Radon and Other Internally Deposited Alpha Emitters"

Radon decay products are where the health threat lies

Radon is a naturally occurring element formed from the radioactive decay of radium-226. There are three radon isotopes, radon-219 and radon-220, which have half-lives measured in seconds and consequently decay before they ever go anywhere, and radon-222. The last isotope has a half-life of 3.82 days and decays by alpha particle emission through a series of solid, short-lived radioisotopes that are collectively called radon daughters or progeny. Two of the daughters in the chain are polonium-218 and polonium-214, which

are also alpha emitters. Polonium-218 has a half-life of 3.11 minutes and polonium-214 has a half-life of just 0.0002 second.

Radon itself is a noble gas, and is, therefore, extremely unreactive. That is why, once formed, radon-222 is free to bubble up out of the ground or dissolve in water without getting trapped anywhere along the way. If radon is inhaled, it is usually immediately exhaled. Because of this, then, it is the two alpha-emitting polonium isotopes that are of greatest health concern. Because they are solids, they can become trapped in airways where their radioactivity can damage nearby cells.

Origins of radon vary, but soil is the largest source

Millions of curies	Annual radon emissions
Soil releases	2400
Groundwater (potential)	500
Oceans	34
Phosphate residues	3
Uranium mill tailings	2
Coal residues	0.02
Natural gas emissions	0.01
Coal combustion	0.0009
Human exhalations	0.00001

Source: National Council on Radiation Protection & Measurements

ters, uranium ore dust, cigarette smoke, and various combinations. By going through these mixtures and then excluding everything but radon daughters, we have found that radon daughters by themselves can produce lung cancer in lab animals."

Cross says that all of the animal studies result in lung cancer risk coefficients in animals, especially rats, that are very, very similar to the coefficients resulting from the underground miner studies. "The data support the linear, no-threshold theory" of cancer formation, he says. Cross points out that the studies show that radon exposure produces cancer no matter how low the levels of exposure, including down to common indoor radon concentrations.

These lowest exposure levels produce effects because the delivery system for the radiation to the lungs is very effective, according to Naomi H. Harley, research professor in the department of environmental medicine at New York University Medical Center and author of much of the 1984 NCRP report on radon. "It's really the short-lived radon daughters that deliver the dose," she says. "Radon itself is radioactive, but the dose really does not come from the gas because of its geometry. Radon as a gas gets in the whole airway where it will be breathed in and out, but the daughters are solids and a fraction of these can deposit on the airways' surfaces as you breathe. It is really an efficient system for irradiating the cells which are crucial to formation of lung cancer," Harley emphasizes. "The range of the alpha particle is very short, about the thickness of a piece of paper, less than 70 μ m. The epithelium where the stem cells are located is only 40- μ m thick. So these stem cells, which generate cancer, are right in the target range."

Although the obvious lung cancer risk is to certain underground miners, the discovery of high levels of radon and radon progeny in peoples' homes has added a heightened dimension to the problem. The Watras home in Pennsylvania that had such very high radon levels sits on a geologic formation called the Reading

Prong, a uranium-rich outcropping of granite that runs northeast from about Reading, Pa., through northern New Jersey and into New York. More than half the homes in the area that have been tested show high levels of radon. For a while, it was hoped that only unusual areas like the Reading Prong would have high readings. But soon, EPA was finding radon all over the country.

EPA has established a radon concentration of 4 pCi per L of air as an "action level" for homes and buildings. According to the agency's risk projection, if a person is exposed to this level of radon and radon progeny for a lifetime (70 years) there is a 1 to 5% chance that that person will die of lung cancer. The choice of 4 pCi per L has received criticism from many areas. EPA does not consider this a safe level of radon concentration, but it is lower than that proposed by some other organizations. The 1984 NCRP study, for instance, says that 8 pCi per L of air is an acceptable level for homes. One reason for the 4 pCi-per-L level is that it is the concentration EPA recommended for homes that were built on contaminated sites from uranium mill tailings or reclaimed phosphate mining areas. These had been thought to be special cases, and perhaps the risk was set higher than it would have been for the general population. To change the radon level on homes now and recommend a lower one would be unacceptable to those living on the contaminated sites.

EPA also uses this 4 pCi-per-L concentration because it is a level that can be achieved with practical remedial work to a home with higher concentrations. "We took a look at how achievable reducing radon concentrations was, and it was pretty easy to get houses down to 4 pCi per L," Guimond says. "We had not done much research at that time on naturally occurring radon in houses; most of our data were on houses we had dealt with in Colorado and Florida. So the concentration we set was, to a great degree, based on information as to what was then technologically achievable." He adds that when the decision was made, it

Variety of kits to detect radon levels in the home are offered by a number of companies

Many brands of detection kits are available to determine radon concentrations in the home. The kits are usually of two types, short term and long term, the major difference being the reliability of results.

The short-term tests usually rely on activated charcoal to collect the radon daughters over a period of two to four days, after which the container is sent to a company that measures the radioactivity by counting gamma rays from radon daughters lead-214 and bismuth-214. Then, taking the length of exposure into account, these data are back-calculated to determine radon concentration.

The long-term test is called a track etch monitor and uses a piece of special polymer film on which an alpha particle can make a "track." After leaving the sample for a minimum of three months, but for up to a year, the film is etched with sodium hydroxide, which makes the tracks big enough to count electronically. Based on the length of exposure, the radon concentration can then be calculated.

If done very well, under controlled conditions, both types of detectors give reasonably accurate measurements of radon levels. The major problem with the short-term test is that radon concentrations in the home can vary considerably, from day to day or week to week. One sample taken in winter may be much higher than a similar sample

taken in summer. Or a measurement made during a dry spell can be higher than one during a rainy period.

The Environmental Protection Agency suggests that several short-term tests be made to get an accurate value. But a single test is useful to see if radon concentrations are really excessive.

Long-term tests, although generally giving good average values, are not as accurate at very low levels of radon.

EPA has instituted a program to test radon detection devices to make sure they meet a minimum standard. These radon measurement proficiency programs send samples of known radiation levels to companies requesting to be certified, and the analyses are checked to see if the companies obtain values within 25% of the true value. The director of EPA's Office of Radiation Programs, Richard J. Guimond, says that this much variability has no effect on whether a home has high radon levels.

"We set up the program so people would still make the right decision even if the measurement company was off by plus or minus 50%, or even 70%," Guimond says. "We set the recommended measurement scheme up to be conservative. By setting up the sample in the basement with the doors and windows closed, we generally believe the reading will be a factor of two to four higher than you would get over an extended period of time averaged over all levels of the house. So, for example, if

somebody gets a reading of 6 pCi per L, and the measurement company is off by 25%, then the value is between 4.5 to 7.5 pCi per L." But if the value is really only half that much, or around 3 pCi per L, extended measurements in the house would determine that. "So the conservatism is built in," Guimond says.

One public interest group, Buyers Up, a spinoff of Ralph Nader's Public Citizen organization, tested some companies for radon test accuracy and concluded that most did poorly. It was a quick and dirty test in which seven companies were each sent eight samples, and the results were not encouraging. Public Citizen says three of the companies "failed" the test, with errors ranging from 28 to 67% higher than the approximately 20 pCi-per-L samples used. As a result, the citizen's group called for greater regulation and more stringent controls on these companies from EPA.

The seven companies in that one test are just a tiny fraction of the companies formed to do radon measurements. Larry Siegelman, publisher of Radon Press Inc., in Alexandria, Va., has been trying to keep track of the industry's growth. "As of last December," he says, "we estimated there were between 2500 and 3000 companies doing radon tests, and, if everyone follows up on EPA's recommendation that they get their houses tested, we project about \$4 billion in

could not be shown feasible to lower average home levels to 1 or 2 pCi per L of air.

With the concept that homes should have radon concentration no higher than 4 pCi per L firmly in mind, the agency had to decide what it could do. At the time, in the early 1980s, there was a severe paucity of funds for the radiation programs. Budget deficits were straining EPA's resources. And, Guimond says, Congress was a little leery about a widescale program. "There was uncertainty about what the federal role should be in cases like this," Guimond explains. "Some lawmakers were reluctant because of the question of should the government get involved with people in their individual homes. And, if the problem was as big as we thought, there might be a hue and cry for a federal bailout, something akin to a Superfund for each homeowner."

The publicity surrounding the high levels in homes on the Reading Prong in 1985 forced the government

to move. With what funds it had, EPA began measuring radon levels in homes and working on radon mitigation techniques. Other researchers, some of whom had been studying radon and its effects for a long time, also got involved. The Energy Department, Department of Housing & Urban Development, Farmers Home Administration, Veterans Administration, and National Park Service all have initiated programs principally aimed at determining radon levels in homes in various areas of the country.

Most studies are finding radon everywhere. EPA's studies have been the most extensive to date, mainly because Congress gave the agency the mandate and the funds to do a pair of studies of radon concentrations when it reauthorized the Superfund law in 1986. The study currently under way is a state-by-state short-term look at radon level in counties. The tests are all short term and measurements are taken in the lowest levels of the home, usually the basement. To date,



Home radon detectors come in two types: long-term track etch (above) or short-term charcoal canister (right)



C&EN staff photo

revenues over the next three or four years." If the growth continues as it has over the past year, Siegelman says, the number of companies in the business could increase 300% in the next year.

EPA says that it investigated only about 1500 testing companies in the latest round of its certification program. Of these, 700 were primary companies—that is, they do their own manufacturing and analysis—and the rest secondary companies. In response to the criticisms of this program, and at the suggestion of its science advisory board, EPA is making some adjustments to this program. Among its adjustments will be more blind testing of measurement companies, requiring only the primary manufacturers to be tested, and making sure the secondary firms meet administrative requirements.

If detection tests reveal a high level of radon in the home, EPA recommends doing some sort of mitigation. The agency has published a handbook on this as well, called "Radon Reduction Methods." Reduction methods range from such simple techniques as natural ventilation—opening windows—to block-wall ventilations, which EPA estimates could cost up to \$5000. According to Naomi T. Harley, research professor in the department of environmental medicine at New York University Medical Center, who is doing detailed research on how radon gets into homes and how to eliminate it, the method that is effective most often is subslab ventilation. In this technique, pipes are inserted through the concrete basement slab, and radon beneath the house is drawn up through the pipe by a fan and vented away from

the house. EPA says the method can cut radon concentrations 90% or more.

Harley, based on her experience, would like to see national legislation regarding radon in houses. She thinks new homes should be required to be built on a good, porous base of crushed rock or its equivalent, so all gas underneath the house could be vented easily. If all homes were built this way, no new houses would have radon problems. Older homes would have to be measured for radon when bought or sold, eventually identifying and correcting the problems in these houses.

Radon also gets into the home in water, especially if groundwater is the source. According to Guimond, however, this is a very small risk compared with the radon that comes into the home from the ground. "But people are very concerned about their water in the U.S.," Guimond says. "Maybe one third of the population does something about its drinking water—buys bottled water, uses filters, or something." He emphasizes that even though water concentrations of radon can be very high, even thousands of picocuries per liter of water, it is not ingestion of radon that is a health problem, but radon in the air. "As a rough rule of thumb, we divide the concentration of radon in water by 10,000 to estimate how much gets into the air. So a concentration of 1000 pCi per L in water would only add about 0.1 pCi per L to the air. It is a concern we have that people will be more worried about their water than their air," Guimond says.

EPA has announced results for homes in 17 states. By the end of this year, it will have results for eight more states. "The state survey," Guimond says, "is to help each state set its own priorities as to what to do." A national survey also has begun. "We placed in 5000 homes randomly selected across the country, detectors on a slightly different basis," he says. "The detectors will be in place for a whole year at every level in the house. In addition, we will be getting information on lifestyle, how much time is spent in the basement, and how the house is constructed." Data will take about a year and a half to collect.

When EPA announced its latest results from the state survey in September last year, it made the pronouncement that has created the biggest activity around radon so far. EPA Administrator Thomas, with the support of Vernon J. Houk, assistant surgeon general for PHS, proposed that every home in the U.S. be tested for radon. This recommendation was made be-

cause EPA is finding radon concentrations in homes exceeding its 4 pCi-per-L action level virtually everywhere, and it is impossible, according to the agency, to know which houses will have the higher concentration. The only way to find out, then, is to test every house. There are about 65 million houses in the U.S., and only a few thousand have been tested so far.

This proposal has created a lot of consternation. Basic questions about EPA's whole program have been raised: How valid are the kinds of readings EPA is taking? How accurate are these short-term tests? And are people being frightened by an overcautious agency not used to handling risks of this magnitude?

Inasmuch as most of EPA's tests so far have been just short screening tests in the basements of houses, there is some doubt whether these numbers should be used as a basis for making decisions about an entire house. EPA admits they should not. In its "Citizen's Guide to Radon," the agency says, "The screening

How to keep the working levels separate from the picocuries

Radon measurements are most often reported as either picocuries per liter or working levels. These units, although sometimes used interchangeably, are not equivalent. And in Europe, even different units, based on SI names, are used.

The curie is the unit of radioactive decay defined as 3.7×10^{10} disintegrations per second. A picocurie (pCi) is one trillionth of that. In SI units, nuclear disintegrations are measured in becquerels (Bq), where 1 Bq equals 1 disintegration per second, or about 27 pCi. For radon measurements, which are given as picocuries per liter of air, this means that each picocurie is about two radon atoms decaying per minute in a liter of air.

Picocuries are technically accurate for measuring actual radon gas con-

centrations. However, radon's half-life is less than four days, and it is radon's decay products that contribute more to the radioactive dose a person receives than the gas itself. To measure this, a new unit was devised for the underground miner studies, one that reflected the radioactive dose received from exposure. That unit is called a working level. It is the total energy deposited by all the subsequent decays of the radon daughter nuclei, and is defined at 130,000 MeV of alpha particle energy dissipated in 1 L of air. When equilibrium factors are included, the energy of 1 working level equals that from 200 pCi per L of radon progeny (but just 100 pCi per L for radon gas).

For simplicity's sake, the Environmental Protection Agency refers to the radon daughter number as radon

concentration, because most of the devices used for home samplings actually measure the radon progeny concentrations. There is no SI equivalent of working level, but it works out to 3700 Bq per cubic meter or 2.08×10^{-5} joules per cubic meter.

Cumulative exposures to radon are measured in working-level months, which is defined, for the miner, as exposure to 1 working level over a 170-hour working month. For example, if a miner had been working for four months (at 170 hours each month) in an environment that had 20 pCi per L of radon progeny, he or she would be said to have accumulated 0.4 working-level month of exposure. Most scientific studies on the health effects of radon exposure use cumulative doses expressed in working-level months.

measurement is not a reliable measure of the average radon levels to which you and your family are exposed." And, although the agency says that a finding of high levels—that is, greater than 4 pCi per L—should be followed up with additional testing, this often isn't conveyed to the public in newspaper and television accounts of EPA suggestions.

Anthony V. Nero, a researcher for the indoor environment program at Lawrence Berkeley Laboratory of the University of California, Berkeley, thinks EPA is misinterpreting these data. "When EPA says that 20 to 30% of the homes exceed their action levels, most of these levels are just basement concentrations," Nero says. "And this is not what the action levels are all about." Guimond admits that using basement levels generally overestimates averages, but says "that is to give screening measurements that are conservative values in order to minimize false negatives." He adds that individuals with high values in their homes are encouraged in the EPA literature to ask for advice from state or local health officials who have been schooled in testing for radon. "Unfortunately, people don't read much of the stuff we hand out," Guimond admits.

Nero and other scientists, such as Bernard L. Cohen of the University of Pittsburgh, who are doing home radon measurements, think EPA's numbers are just too high. Instead of the 4 pCi-per-L average EPA is finding in basements, they conclude that average indoor radon levels, measured over the long term, are about 1.5 pCi per L. Nero's research finds that only 2% of the homes in the U.S. would have radon concentrations at or above 8 pCi per L, which he believes is a more realistic level at which to become concerned. In addition to this, Nero says his data show that the

homes with the highest radon levels are tightly clustered. Disagreeing with EPA's call for all homes to be tested, Nero says it would be much more effective to identify the areas where radon concentrations are higher than normal and monitor the houses there.

Cohen's data have gained some notoriety because they show some effects contrary to what EPA says it has been finding. He has compiled radon measurements in homes in 411 counties in the U.S. that he claims show a negative correlation between indoor radon concentration and lung cancer. Using data from several state testing programs, from that he collected by sending out free testing devices, and from people who paid him to test their homes, Cohen says he consistently gets results that show lower levels of lung cancer than expected when low levels of radon are measured. In high radon areas of the U.S., for instance, where the usual risk estimates would predict a 200% increase in lung cancer for women, Cohen reports a decrease of 18%. Separately, when he compares the areas of the U.S. with the lowest and the highest female lung cancer rates, he finds that the radon levels are lower in counties with high lung cancer rates and higher in counties with low lung cancer rates.

EPA doesn't think these data can hold up to close scrutiny. Guimond says he is disappointed that, when dozens of investigators over the years conclude there is increased risk from radon exposure, this one contrary study is given so much attention. "Bernie, out of the blue, takes this one weak data set, he makes some back-of-the-envelope calculations and comes up with a theory that people are grasping at like crazy, like it's definitive." Guimond says some of the problems he sees with these data are that Cohen mixes various

types of houses, does not use all randomly selected houses (EPA finds that people who choose to have their house tested for radon have higher levels than those selected randomly), and uses cancer death data from 1950 to 1969 in contrast to radon measurements taken from 1982 to 1988. Although Cohen's report tries to take these confounding factors into account, Guimond says one has to be very, very cautious about these kinds of general extrapolations.

Cohen says that one explanation for his results may be a combination of the linear, no-threshold theory of cancer formation with hormesis. Hormesis is the concept, roughly, that a toxic agent can have a beneficial effect on a body at levels below those at which harmful effects are produced. In the case of radon, some scientists believe there is a hormesis effect at low levels and that this is shown in Cohen's data. T. Don Luckey, retired professor of biochemistry and nutrition from the University of Missouri, Columbia, school of medicine, maintains that many health physicists are coming around to this position. "Low levels [of alpha radiation from radon] probably stimulate the body's defense mechanisms and you end up with less cancer," Luckey says. He says there are data showing this effect, especially with gamma or x-rays, but not much with alpha particles yet. Cohen mentions the hormetic effect in his research, saying that at low doses and low rates, hormesis is consistent with his data.

Some animal data show unusual effects from radon exposure. Cross at Battelle says at high levels of exposure there appears to be some concentration where radon daughters' ability to produce cancer is the most effective. Below that concentration, the cancer-causing ability seems to decrease. Certain animal data, Cross says, "suggest that there is a given exposure rate and a particular exposure level that is most efficient for producing cancer. And when you go down from that rate or up from that rate the efficiency of cancer production falls off. What we have to do is continue to work to see if, as we protract exposures to extremely low levels, we might be going to a no-effect level. It's way too early to say that, however."

Another interesting effect Cross mentions concerns the risk dependency of unattached radon daughters. "When unattached daughters are inhaled into the lungs, the deposition frequencies are 100%. When daughters that are deposited on dust particles in the air are inhaled into the lungs, only a few percent of them will be deposited along the tracheal-bronchial surfaces where humans get lung cancer. Where this is important for indoor radon, as opposed to underground mines," Cross maintains, "is that you have much cleaner air in most houses. So one must consider unattached daughters when estimating the risk from indoor radon exposure."

The effect of smoking on lung cancer risk from radon is significant. The NAS radon study indicates that the risks from radon exposure are multiplied when the person is a smoker. The study admits, too, that the estimates of risk it makes may be more applicable to smokers than nonsmokers in general, because

there are very few nonsmokers included in the lung cancer mortality data from underground miners. William Mills, a senior technical adviser for Oak Ridge Associated Universities in Washington, D.C., and past director of the criteria and standards division of EPA's Office of Radiation Programs, thinks the smoking factor has been way underplayed. "My biggest concern is that the risk to the nonsmoking population is much less than to the smoking population," Mills says. "Yet when you talk about average lung cancer deaths caused by radon in the U.S., it's weighted to the smoking population. The smoker is already at such high risk of lung cancer from the smoking, I'm not sure public policy should be based on what the risk to the smoker is." Some people believe that the lung cancer risk from radon is so high for smokers and so low for nonsmokers, that even if the radon concentration in all homes was lowered to less than 4 pCi per L there would be no noticeable drop in lung cancer death statistics.

Epidemiology studies under way at the National Cancer Institute may shed some light on the health hazard from radon in homes. One study to be completed this year involves 1600 women from New Jersey, half of whom had lung cancer. Another similar study is being carried out in Missouri, this one with 350 women with lung cancer who had never smoked. Two other international studies are being run at NCI. One is in Stockholm because of the very high radon concentrations found in that city; the other is in the city of Shenyang, China, because the highest rate of lung cancers in the country is found there. Data from these studies are expected to be available within a year.

Most researchers concur that radon in the home can be a problem. Levels in the 10 to 20 pCi-per-L range over a lifetime can equal the exposure that miners received where high lung cancer rates have been observed. There is some feeling, however, that EPA may have set its action level too low. Although nearly all studies agree that there is only about a 1% risk of getting lung cancer at 4 pCi per L, EPA may not be handling the concepts involved properly.

Berkeley's Nero says, "This is a much bigger risk than EPA is normally dealing with. They are not used to thinking in terms where an average risk is 1%. There is a real contrast between a situation where one is controlling a pollutant concentration in a common resource like the outdoor atmosphere and the kinds of risk people, knowingly or not, accept every day in their houses, cars, or workplaces. There, ordinary risk levels are higher and that's because those are the places we enclose ourselves, for our own benefit. The whole risk/benefit equation is completely different in those circumstances than it is when considering something like the outside air." As an example, Nero points out that people in a home with an average concentration of 1.5 pCi per L have about the same risk of lung cancer as they have of dying from an accident in the home. The excess risks are really to persons living in the 20 pCi-per-L and higher range, and that should be where EPA is concentrating its efforts, he says. □

Aromatics Price Increases Forecast To Ease

Catch-up of supply to demand is expected to diminish selling prices of benzene, toluene, and xylenes

Bruce F. Greek, C&EN Houston

A widely cycling relationship between supply/demand and price for major-volume aromatics—building blocks for a huge array of other chemicals—may be headed for another turning point. Strong demand, especially for benzene, carried over from last year and a few supply problems have pushed prices this month for benzene, toluene, and mixed xylenes to their highest levels in more than a year. Benzene, for example, currently is selling for \$1.90 per gal on a contract basis, compared with \$1.10 about six months ago. However, the current prices will be short-lived, according to industry sources.

Unless more plant problems crop up and export demand for aromatics derivatives spurts, supply will move closer to demand. Prices, particularly spot prices, may weaken during the second quarter. This month, sellers of benzene have noted that buyers are reluctant to take more product than is needed for immediate conversion to derivatives. Buyers also have noted that current prices are above levels needed to bring aromatics out of the gasoline pool at current gasoline prices at refineries.

Both the buyers of aromatics for nonfuel uses and the petroleum refiners are aware that aromatics prices could stay above last year's levels during the summer driving season. Refiners are expected to

have to struggle to meet the anticipated volume and octane-value demand for premium unleaded gasoline. Premium gasoline currently has gained about three times the share of the total gasoline market expected by petroleum refiners, based on historical demands for premium gasoline.

Despite the demand that aromatics be left in the gasoline pool to give better octane value, output of aromatics by separation and purification from catalytic reformat and steam-cracking product streams will increase over 1988 levels. Benzene recovered from these streams, and other minor amounts from coking of coal and from styrene manufacture, will total more than 1.7 billion gal in 1989, up 4 to 5% from 1988 production, which is estimated to have been more than 1.6 billion gal. If 1989 benzene production does exceed 1.7 billion gal, it will top the all-time record output of 1.67 billion gal in 1979.

Output of toluene and mixed xylenes for nonfuel uses are likely to rise by about the same fraction. Toluene recovered from its sources for nonfuel uses is forecast to total more than 900 million gal in 1989. That output, however, will be less than

the historical record of more than 950 million gal produced in 1987, according to the International Trade Commission.

This year, production of mixed xylenes (ortho, meta, and para isomers and a small quantity of ethylbenzene) is forecast to reach about 850 million gal. Forecasts of xylene production involve some uncertainty because variations in the feedstocks sent to reformers and steam crackers, and in the operating conditions of those units and extraction units, can change the aromatics product mix. This year's production of mixed xylenes will be well below the record level of more than 1 billion gal recovered in 1979.

Capacity to produce benzene, toluene, and xylenes far exceeds actual production. Some of those aromatics are contained in the feedstocks to reformers and steam crackers and may pass through processing unchanged. Conversion of other feedstock components to aromatics depends heavily on operating conditions, especially in reformers. Higher aromatics output can be obtained by increasing the severity of operation at the cost of greater loss of the feed. Currently, because of increased sales of higher octane gasoline, reform-

U.S. aromatics nonfuel supply/demand

Refineries provide 75% of U.S. nonfuel aromatics supply

Source	Millions of gal
Catalytic reforming	2200
Steam cracking	675
Coal coking	50
Styrene coproduct	25
TOTAL	2950

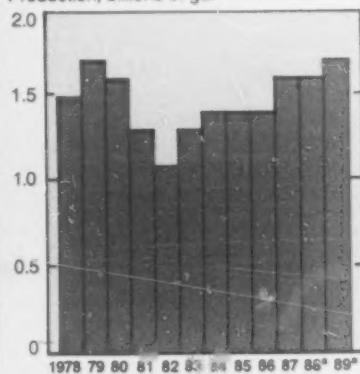
Benzene accounts for one third of U.S. nonfuel aromatics demand

Aromatic	Millions of gal
Benzene	1100
Toluene^a	900
Xylenes^b	850
TOTAL^c	2850

Note: Benzene, toluene, and xylenes only. ^a 575 million gal hydrodealkylated to benzene and disproportionated to benzene and mixed xylenes. ^b Ortho, 80 million gal; meta, 15 million gal; para, 750 million gal; remainder consumed as mixed xylenes, mostly as solvents. ^c Balance of exports over imports accounts for difference. Source: C&EN estimates

Benzene output will hit decade-old record

Production, billions of gal



^a Estimate. Sources: International Trade Commission, C&EN estimates

ers are being operated under more severe conditions than during the mid-1980s and are producing more aromatics.

Steam crackers currently are being operated to maximize ethylene production. As a result, feedstocks have been shifted toward light hydrocarbons wherever possible and the output of pyrolysis gasoline containing aromatics is thereby reduced. However, because steam crackers account for a small part (3 to 5%) of total aromatics production, the present changes have only a small effect on total aromatics production.

For chemical and other nonfuel uses, aromatics are removed from reformat and pyrolysis gasoline by solvent extraction. Benzene, toluene, and xylenes are then separated and purified, and the remaining components are returned to the gasoline pool. Recovery and purification capacity also exceeds demand for aromatics by a substantial amount. However, if feed to a catalytic reformer is limited in volume or in aromatic precursors and if operating problems exist with the reformer, then aromatics in the reformat can be down and recovery low.

Of the three major commercially significant aromatics that are chemical raw materials, toluene has the least use, other than for conversion to benzene. About two thirds of toluene removed from aromatics sources is converted to benzene, largely through hydrodealkylation (HDA).

Currently, toluene HDA accounts for roughly a third of benzene production, but it has been in the range of 20 to 30% of production on average during the period between 1975 and 1985.

The share of benzene produced from toluene also will vary widely with selling prices of the two aromatics. At this time, with benzene prices about 60 cents per gal higher than toluene (now about \$1.30 per gal), most operable HDA units are running profitably. The spread between benzene and toluene prices determines whether HDA units will operate. The spread covers processing costs and the difference in value of toluene in other uses, particularly in gasoline. Startup and shutdown of HDA units are done with relative ease and low cost, making the use of these units sensitive to prices.

Part of the rapid increase in the spot benzene price during the fourth quarter of 1988 and the contract price more recently has resulted from a slow restart of HDA units and the problems occurring after the units began operation. Last summer, benzene and toluene prices were so close that many HDA units couldn't be run profitably. Prices of both of these aromatics then began to rise, but their price difference remained small enough that HDA units were not restarted. Late in the

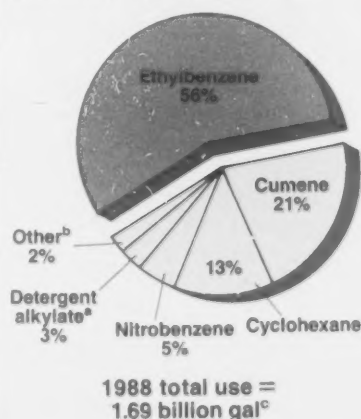
third quarter, demand for benzene use in its three major derivatives—ethylbenzene (for styrene), cumene (for phenol), and cyclohexane (for nylon)—strengthened rapidly, driving prices higher. The delay in getting HDA units started because of the unacceptable selling price differential led to apparent shortages of benzene, resulting in even more price increases. As HDA units were started up, a few experienced mechanical problems. Other units had feedstock limitations because of problems in reformers and in aromatics extraction and purification units providing the toluene feedstock.

So far this year, contract prices for benzene have followed spot prices, suggesting that supply is still lower than demand. Change toward a balance hinges on the largest use of benzene—that of making styrene—according to industry sources. An unusually strong demand growth for polystyrene in 1988, with production up more than 8% through October over 1987, now is forecast to ease because polystyrene capacity has become fully utilized.

Styrene production growth closely matched that of polystyrene for the first nine months of 1988. Some debottlenecking of capacity has occurred and is forecast to continue this year, to add 3 to 5% to capacity. Demand for benzene in this use will rise this year by about half of the growth last year, easing the supply pressure temporarily. However, a large amount of new styrene capacity will be coming on stream in 1990, to add more than 1 billion lb of capacity to the current total of about 8.5 billion lb. That additional styrene capacity will require about 100 million gal more of benzene during 1990.

Both other major uses of benzene—cumene and cyclohexane—grew more slowly last year than ethylbenzene. This year, cumene use is forecast to grow slowly, mainly because of expected lower demand for resins used in plywood and particle board, resulting from lower housing construction. Housing is expected to affect cyclohexane growth similarly, holding down growth in this use of benzene. □

Ethylbenzene dominates chemical uses of benzene



^a Mostly linear alkylbenzenes. ^b Mostly chlorobenzenes. ^c Includes 60 million gal excess of imports over exports. Sources: International Trade Commission, C&EN estimates

Hazardous Waste Management Database Starts To Take Shape

Survey provides data on waste treatment, storage, disposal, and recycling; survey on hazardous waste generation also under way

James Krieger, C&EN Washington

AAAS SAN FRANCISCO

When Research Triangle Institute personnel have finished tabulating the results of two recent surveys later this year, the Environmental Protection Agency will have a comprehensive database for the 250 million to 600 million metric tons of hazardous waste generated annually in the U.S. That database will provide the underpinning for regulatory development under the Resource Conservation & Recovery Act of 1976 (RCRA) and related legislation.

Overall, the effort is a large, multiyear, interdisciplinary project. It is being conducted by the Research Triangle Park, N.C., institute under contract to EPA's Office of Solid Waste and is designed to collect data on the nation's generation and management of hazardous waste.

The survey on management—which covers facilities for treatment, storage, disposal, or recycling (TSDR)—is the first to bear fruit. Preliminary survey results were the focus of a symposium at the annual meeting of the American Association for the Advancement of Science last month. Providing an overview of how the survey was developed and implemented was an EPA-RTI project team headed by EPA project officer James W. Craig and RTI project manager John L. Warren, and including RTI's Danny R. Allen,

Large facilities manage most of the waste



project computer operations manager; Patricia C. Smith, survey operations manager; and Sheryl A. Caldwell, who was in charge of survey questionnaire development.

Between now and June, the schedule for the TSDR survey calls for computer edits, followup, and clean-up of the data, with creation of the final database system slated for July and August. A report with final data likely will be available this summer. The hazardous waste generator survey is ongoing as well, with a final report due late this year.

Meanwhile, the TSDR facility data presented at the symposium, Warren notes, have not been completely edited and reviewed. As a result, numbers are provided for now in ranges rather than point estimates.

As covered by the survey, hazardous waste includes a variety of categories—any waste considered hazardous by RCRA; any waste considered hazardous by a state; any waste considered hazardous in the

state in which it is generated, even if it is not considered hazardous by the state in which it undergoes treatment or disposal; wastes containing polychlorinated biphenyls; wastes containing asbestos; and wastes containing dioxins.

More than two years in development, including pretesting and site visits, the TSDR survey was detailed and comprehensive. The survey questionnaire was mailed out in August 1987, and the full package consisted of 15 different booklets. There was a booklet for each technology used for managing hazardous waste. More than 700 questions and 5000 variables were used to organize the data collected from 2626 TSDR facilities. RTI used computer systems to manage the survey, enter the data, edit the data, and analyze results.

The information requested from survey respondents included general facility information and waste management process regulatory status, commercial availability, and design and operating parameters.

Industrial organics is highest class in hazardous waste volume

Standard industrial classification	SIC category	Hazardous waste volume, millions of metric tons
2869	Industrial organic chemicals	60-80
2800	General chemical manufacturing	40-50
2911	Petroleum refining	20-30
2892	Explosives	10-15
2821	Plastic materials/resins	6-10
4953	Refuse systems (commercial TSDR* facility)	5-8
2879	Agricultural chemicals	5-8
2865	Cyclic crudes/intermediates	5-8
2818	Inorganic pigments	3.5-5
2812	Alkalies/chlorine	2.5-4.5

* Transportation, storage, disposal, or recycling.

Various technologies are used in hazardous waste management

Type of technology or process	Waste volume managed, millions of metric tons
Incineration	0.85-0.95
Reuse as fuel	1-1.2
Fuel blending	0.45-0.6
Solidification/stabilization	0.5-0.6
Solvent recovery	0.7-0.8
Metal recovery	0.4-0.5
Wastewater treatment	350-450
Other treatment processes	1.5-3
Waste pile	0.4-0.5
Surface impoundment	150-225
Landfill	1.7-2.0
Land treatment	0.3-0.4
Underground injection	11.5-13.5

Additional information requested included waste management capacity, planned changes in management capacity, waste quantity and type generated and managed, and tank system design and operating parameters.

As surveys go, the TSDR survey was unique in many ways. For one thing, EPA should eventually receive 100% response, since respondents are required by RCRA to furnish the information, with fines of up to \$25,000 per day possible for nonresponse. However, facilities did have a further incentive to respond—namely, seeing that EPA has information that is accurate for use in developing regulations.

Another unique aspect of the survey is that respondents were guaranteed confidentiality by law. Hence, because of the nature of some of the data being collected, some responses are claimed as EPA confidential business information. Based on EPA requirements, RTI installed a minicomputer (VAX 11/750) dedicated to the hazardous waste surveys to provide secure management of confidential data. According to Warren, the computer facility is the largest of its kind outside EPA that is approved for managing confidential data collected under RCRA.

The nature of the responses adds still further to the uniqueness. EPA considers a respondent's completed questionnaires to be an official legal record of the operations at that facility. Most surveys ask respondents simply to complete questions to the best of their ability. But EPA expects the facilities to portray their

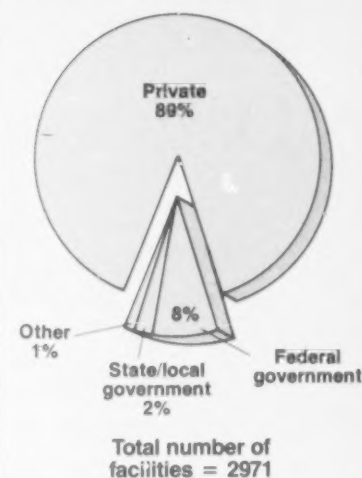
operations accurately, because EPA needs reliable data to defend itself against lawsuits filed to overturn or stay regulations developed using the data.

The survey was lengthy, and it was complete. The entire set of questionnaires added up to more than 500 pages. The technical nature of the requested information required many complex questions. Moreover, unlike previous surveys of hazardous waste management, the TSDR survey requested information not just on the highest volume wastes or largest facilities. It required respondents to provide information on every hazardous waste stream, every hazardous waste management process, and every hazardous waste management unit.

A feature of RTI's approach to the survey is the development of two respondent support systems, a toll-free Survey Helpline and a newsletter called *Survey Update* mailed periodically to surveyed facilities. The Survey Helpline was a network of five WATS telephone lines and six trained personnel operating five days a week. RTI's Caldwell notes that during the first two months of operation, the helpline received about 300 to 400 calls per week. Toward the end of the response period, the number of calls dropped to less than 100 per month.

During the survey, three issues of *Survey Update* were mailed. The topics addressed by the newsletter

Most waste management facilities privately owned



included those relating to major elements of the survey, recurring issues and questions on Survey Helpline, and errors noted in the questionnaires.

The TSDR survey has had a long gestation period. Originally, EPA planned a less extensive survey to support analyses of hazardous waste regulations developed under RCRA. However, EPA's information needs changed significantly with passage of the Hazardous & Solid Waste Amendments of 1984 and the Superfund Amendments and Reauthorization Act of 1986 (SARA).

EPA's Craig explains that the 1984 amendments required new regulations, beginning with restrictions on land disposal of hazardous wastes, and significant modifications to existing regulations, such as revising the ways to determine if a particular waste stream is hazardous. Included in other requirements were the development of standards for managing hazardous wastes in tanks, for cleaning up contamination caused by waste management units, and for performing economic and risk analyses of any regulations developed.

Realizing it needed additional information for aspects of waste management affected by the new legislation, EPA expanded the scope of the initial survey. It increased the size of the survey's universe from 700 facilities to 3000 to support de-

Industrial organics class has most management facilities

Standard industrial classification	SIC category	Number of TSDR* facilities
2869	Industrial organic chemicals	150
2911	Petroleum refining	96
9711	National security	85
4911	Electric services	63
2821	Plastic materials/resins	57
2819	Industrial inorganic chemicals	54
3471	Plating and polishing	45
4953	Refuse systems (commercial TSDR facility)	45
2491	Wood preserving	44
3312	Blast furnaces/steel mills	37

* Transportation, storage, disposal, or recycling.

velopment of regulatory standards as well as economic and regulatory impact analyses.

Then in November 1986 came SARA, which requires states to assess the available capacity for managing hazardous wastes and to site new facilities where needed. As a result, EPA needs to estimate available capacity by state. So the survey sampling plan was stratified by state as well as by type and size of management process.

Craig notes that in addition to using the survey for regulatory development, EPA will use the data for trend analyses, for planning, and for targeting enforcement actions, although no enforcement actions will be undertaken solely on the basis of questionnaire responses. For regulatory development, the data will provide a basis to evaluate capacity available to manage hazardous waste using technologies other than land disposal; develop efficiency standards for waste management technologies used as alternatives to land disposal; develop permitting standards for tanks used to manage hazardous wastes; revise procedures for identifying wastes as hazardous; develop standards for cleaning up contamination caused by waste management units; assess costs, risks, and impacts of hazardous waste regulations; and evaluate each state's plans to provide sufficient capacity to manage hazardous waste. □

Chemical warfare organization debated

Two policy analysts with the U.S. Institute of Peace propose that an International Chemical Warfare Authority be set up as a means of short-circuiting what they perceive as flaws in current negotiations in Geneva on a global ban on the possession, production, and use of chemical weapons. If such a global ban is feasible, which they question, it will not be negotiated for several years. In the interim, they offer their proposal as one possible way of stemming the spread of chemical weapons.

As envisioned by Robin Ranger and Raymond Cohen, both Jennings



Ranger: unenforceable limits

Randolph Peace Fellows at the peace institute, the authority would consist of:

- A governing council of member states, composed initially of the two superpowers and major industrial nations.
- A permanent secretariat.
- An inspectorate, which would investigate charges of violations. It would not necessarily be linked to the United Nations. It would monitor worldwide flows of precursor chemicals and chemical weapons-making equipment. And it would have chemical weapons and equipment for defensive and offensive purposes at its disposal, which it could supply to states victimized by chemical warfare.

Ranger and Cohen presented their proposals for critique at a workshop sponsored by the institute in Washington, D.C., late last month. They used the public forum as "a heuristic device," Ranger said, and a means of provoking "fresh thinking in a debate that has stagnated," Cohen added. Their proposal met with only mild acceptance.

The analysts are trying to carve out a middle ground between a global treaty completely banning these weapons, and independent policies of deterrence. "Politically and practically speaking the basic proposal is a nonstarter," says Brad Roberts, executive editor of *The Washington Quarterly* and an invited discussant.

Underlining the *raison d'être* for the proposal, Ranger cites recent outbreaks of chemical weapons use as illegal breaches of the 1925 Geneva Protocol. This leads him to distinguish between the ability to verify such breaches and the inability to enforce compliance with such a longstanding treaty.

Following the logic of his thinking, Ranger asks if it is "feasible to negotiate limits on chemical and biological weapons which cannot be enforced?" He answers, in part: "If the U.S. and its allies find that they cannot enforce a ban on the first use of chemical weapons, then it is difficult to say how they would expect to enforce compliance with a ban on the manufacture and production of chemical weapons." The ongoing talks in Geneva are trying to develop a global, verifiable ban on the production and possession, as well as use, of chemical weapons.

Elisa D. Harris, a guest scholar at Brookings Institution and another discussant, finds it "useful to distinguish between compliance and verification." But she says, "It is important not to exaggerate or overstate" breaches in compliance.

"One could argue that there have been remarkably few violations of the Geneva Protocol," Harris continues. She notes that there have been about 200 conflicts since World War I when chemical weapons could have been used and were not,



Harris: only five confirmed violations